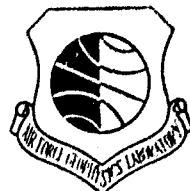


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Survey of Sensors for Automated Tactical Weather Observations.

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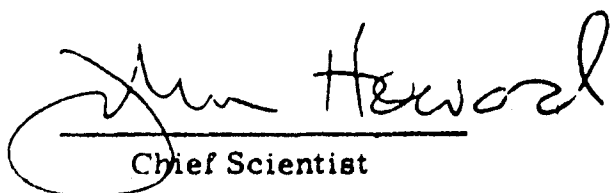
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Sensor selection will include both accuracy and the ability to operate trouble free over a wide range of environmental extremes. When appropriate, in-house programs will be initiated to correct deficiencies. During the coming year, field tests and intercomparisons will be made of selected sensors. Instrumentation will eventually be integrated into an automated system with local and/or remote display of weather elements tailored to user requirements.

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Summary

A program has been initiated at the AFGL to develop an automated tactical weather station for bare-base airfield operation. In the first phase of the program, a survey has been made of the state-of-the-art to identify instrumentation suitable for such a system. Both government inventoried equipment and commercial equipment have been considered. Military equipment will generally be given first consideration due to their availability, demonstrated history of performance, and familiarity to operators in the field. General criteria to be used in sensor selection will include suitability to automation, method of measurement, accuracy, and the ability to operate over a broad range of environmental extremes. During the coming year, field testing of candidate sensors will be conducted. A demonstration system incorporating selected instrumentation will be assembled.

Preface

This report by the Air Force Geophysics Laboratory (LYU) is intended to acquaint readers within the Air Force organization, of the direction and considerations contemplated in the selection of meteorological sensors for use in an automated tactical weather station. No reference shall be made to the AFGL in advertising or sales promotion concerning any proprietary product discussed in this report which would imply endorsement of that product by this organization. The fact that specific products may not have been mentioned should not be constructed as a reflection upon their quality.

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Survey of Sensors for Automated Tactical Weather Observations

1. INTRODUCTION

The Air Weather Service (AWS) is required to provide accurate and timely observations and forecasting support to Air Force and Army units in tactical bare-base environments. The requirements for such support is documented in Required Operations Capability (ROC 801-T1), Automated Weather Distribution System (AWDS). Though the requirement for this type of service increases because of anticipated greater reliance on weather information during tactical operations, the manpower that will be available to perform the various tasks is expected to diminish. Therefore, in order to provide this support and to perform efficiently, it is vital that AWS have a modern automated system for acquisition and processing of meteorological data.

The Air Force Geophysics Laboratory (AFGL) initiated a program to assess current military inventoried weather sensors for their suitability in automated tactical bare-base operations. Concurrently, a survey was conducted of state-of-the-art meteorological instruments and measuring techniques. An overall evaluation was made of the current status of each category of sensors. It was determined which military inventoried sensors are adaptable to automated tactical operations. Where deficiencies exist, it was ascertained whether suitable alternative commercial sensors are available.

(Received for publication 25 June 1980)

In the next phase of the program, field testing and intercomparisons of a number of sensors will be made at the AFGL Weather Test Facility (WTF), Otis AFB, Massachusetts and at AFGL Hanscom AFB, Massachusetts. Candidate sensors will be selected based on the test results. Techniques for automation of the candidate sensors will be investigated. The program will lead to a demonstration model of an automated tactical base-base weather observing system.

2. TEMPERATURE AND DEW POINT

Often, the measurement of temperature and dew point is provided by the same instrument. In this report, therefore, both measurements will be considered together.

2.1 General

2.1.1 DEW POINT

A wide range of techniques exist for the measurement of humidity. A compilation of methods may be found in a monograph by Wexler.¹ Most of these methods are highly specialized or are not suitable for meteorological application because of limited range, accuracy considerations, or their ability to be readily automated. Only two of these techniques, the lithium chloride dewcell and the optical dew point hygrometer, will be given consideration and discussed in detail. Instruments utilizing these techniques find important application in industry and are widely used in the AWS.

Optical dew point hygrometers represent an important class of instrumentation whose performance can be directly traced to first principles. In typical commercial instruments, a polished mirror surface is thermoelectrically heated and cooled to maintain a thin layer of condensation. The mirror surface is illuminated by a light source and is monitored by a photodetector in an optical bridge network. The detector output controls a signal proportional to the observed light level which is also used to vary power to the thermoelectric cooler. A rate feedback loop causes the system to stabilize upon a thin layer of dew or frost. At steady-state, the temperature of the mirror surface is at the dew (frost) point temperature and is measured by a precision temperature element embedded beneath its surface. Dew point hygrometers can routinely operate trouble-free for extended periods of time. Of prime concern with these instruments is the condition of the mirror surface. If the surface has accumulated dirt, salt, or other airborne contamination, the

1. Wexler, A. (1970) Measurement of humidity in the free atmosphere near the surface of the earth, AMS Meteorological Monograph, Vol. II (No. 33):262-282.

electronic circuit will perceive this condition as condensation and will increase the temperature of the mirror in an attempt to reduce it. For small amounts of contamination, this will result in only a small positive dew point bias. As the contamination becomes more pronounced, the bias error will increase significantly and will eventually reach the point where the indicated temperature is higher than the free air temperature. Manufacturers of optical dew point instruments resort to various techniques to minimize or compensate for this problem. The most satisfactory approach involves an automatic rebalancing of the bridge network after the initiation of a heating cycle to clear the mirror of condensation. However, contamination buildup will eventually prevent the circuit from being rebalanced, requiring that the optics be cleaned. The interval between cleanings will depend upon the dirtiness of the atmosphere being sampled and can vary between several days and a few months. Periodic mirror cleaning is a necessary part of any dew point hygrometer maintenance program.

Though the current listed accuracy of AWS optical dew point sensors is about 1°C , this specification could be somewhat upgraded. The better commercial instruments claim uncertainties between 0.2°C and 0.5°C . Improved dew point measurements might be of value in weather forecasting. In the tracking of air masses, for example, dew point is probably no less important than free air temperature. Along with temperature, it shows the degree of air saturation and is often representative of the air mass while the temperature is locally affected. The use of dew point in predicting fog and frost formation can also be of critical importance to Air Force and Army tactical operations.

The dewcel hygrometer, as typified by the AN/TMQ-11 Humidity-Temperature Measuring Set, uses a cylindrical tube covered with a wicking material and wrapped with a bifilar wire winding. The wicking is coated with a solution of lithium chloride. When a voltage is applied across the electrodes, current will flow in the circuit if the vapor pressure of the film is in excess of the ambient partial pressure of water vapor. A heating current will cause the salt film to dry out until steady-state conditions have been attained. Conversely, if the ambient vapor pressure is higher than that above the salt film, water vapor will be absorbed by the film until current is again able to pass, thus repeating the heating cycle. The temperature of the probe can be related to the dew point temperature. Since the system has capability only for heating the film, operation of the system is restricted to probe temperatures above ambient. For lithium chloride salt solutions, the lowest value of relative humidity that can thus be measured is about 12 percent for ambient temperatures above 60°C and gradually rises until at -50°C it becomes 100 percent. To obtain reliable results from dewcel measurements, considerable care is required in cleaning and resalting the probes.²

² Weiss, B. D. (1968) Error Analysis of the Humidity-Temperature Measuring Set, AN/TMQ-15, AFCRL-TR-68-0154, AD 669095.

2.1.2 TEMPERATURE

Air temperature is usually measured with mercury thermometers, resistance thermometers, thermocouples, or thermistors. With the exception of the mercury thermometer any of these sensors could find application in an automated tactical weather station.

Specified accuracies for temperature sensors in AWS inventoried systems or instruments are approximately 0.5°C. This accuracy can also readily be met by currently available commercial thermometers. If only temperature itself is required, it is seldom meteorologically necessary to be more accurate. When relative humidity is derived from measurements of free air temperature and dew point, however, it is often required to know temperature to within a few tenths of a degree.

A potential source of error in the measurement of ambient temperature using in-situ thermometers is radiation. Exposed instruments are subject to significant solar radiation errors, while shielded instruments are prone to wall-effects and, if aspirated, from heat contamination from fans or motors. Through adequate shielding and proper design, the solar radiation error can be reduced to less than a few tenths of a degree. Typical temperature probe construction includes multiple-walled aspirator channels or silvered-glass vacuum sleeves.

Air exiting from either the temperature or dew point sensors will usually be at a temperature distinct from ambient due to contact with duct wall surfaces and heat from motors. The exited temperature-modified air must be sufficiently removed from the temperature probe inlet to insure that the free air sample is not contaminated. In practical probe construction, this effect can be kept to a minimum. It should be noted that, when using an aspirated probe, heat contamination does not normally pose a problem in the measurement of dew point. The dew point is a function of the specific humidity which, if not altered, is unaffected by changes in ambient temperature.

2.2 Equipment

2.2.1 INVENTORIED EQUIPMENT

Temperature and dew-point equipment presently in the AWS inventory includes AN/TMQ-11, Humidity-Temperature Measuring Set, Tactical; AN/TMQ-20, Temperature-Dew Point Measuring Set; and AN/TMQ-22, Measuring Set, Meteorological.³

3. Air Weather Service meteorological sensors and related equipment, AWS Pamphlet 105-53, September 1978.

The accuracy specifications for these systems are shown in Table 1. Though the AN/TMQ-22 Meteorological Measuring Set also provides sensors for the measurement of winds, pressure, and precipitation, only the specifications for temperature and dew point are shown.

Table 1. Temperature and Dew Point Accuracies for AWS Inventoried Systems (From AWA pamphlet 135-53)³

AN/TMQ-11 Humidity-Temperature Measuring Set, Tactical	
Temperature	$\pm 1^{\circ}\text{F}$ (-80°F to +130°F)
Dew Point	$\pm 2^{\circ}\text{F}$ (-50°F to 90°F)
AN/TMQ-20 Temperature-Dew Point Measuring Set	
Temperature	$\pm 1^{\circ}\text{F}$ (-80°F to +130°F)
Dew Point	$\pm 1^{\circ}\text{F}$ (+32°F to +120°F)
	$\pm 2^{\circ}\text{F}$ (-20°F to +32°F)
	$\pm 4^{\circ}\text{F}$ (-80°F to -20°F)
AN/TMQ-22 Measuring Set, Meteorological	
Temperature	$\pm 0.9^{\circ}\text{F}$ (-58°F to +122°F)
Dew Point	$\pm 1.8^{\circ}\text{F}$ (-58°F to +122°F)

The AN/TMQ-11 uses the lithium chloride dewcel for humidity sensing and has a resistance thermometer for temperature readout.

The AN/TMQ-20 is a Peltier-cooled optical dew point hygrometer with a platinum resistance thermometer for free-air temperature.

The AN/TMQ-22 has a Peltier-cooled optical dew point hygrometer with a thermistor for the free-air temperature.

2.2.2 COMMERCIAL EQUIPMENT

The specifications of a number of commercial optical dew point systems were examined. Two of these systems have been selected for further testing and evaluation for use in a tactical weather station, namely, the EG&G Model 220 and the GE Model 1200MP. General specifications for these systems are given in Table A1 of Appendix A.

A preliminary field test intercomparison of the above sensors, along with an EG&G Model 110 (no longer commercially available) was conducted during the spring of 1979. The Model 110 system has been used extensively at AFGL in a number of research programs and has a good record of performance. It was used in this test to provide additional data and to give insight into any discrepancies which might arise

during testing between the EG&G 220 and GE 1200 MP systems. The three systems were operated in close proximity to each other on top of a building at AFGL.

Figures 1 and 2 show portions of the data. Sensor outputs were scanned and recorded on magnetic tape once every 9 seconds. Each data point in the figures represents a 15-min average. Qualitatively, the tracking between data points was usually that which was to be expected considering the stated accuracies for the instruments. Some anomalies in dew point were observed in both the EG&G 220 and the GE 1200 MP. Throughout the test period, the EG&G 110 was always in very close agreement with at least one of the other two instruments and appeared to be operating correctly.

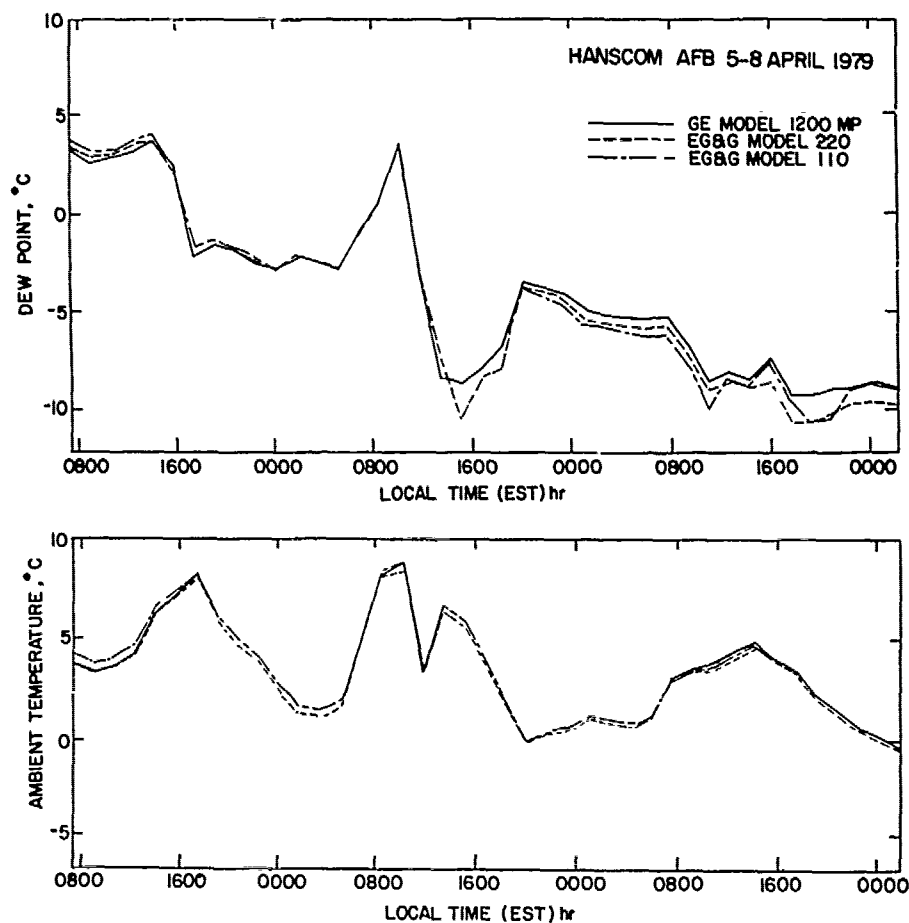


Figure 1. Comparison Field Tests of Three Temperature-Dew Point Systems

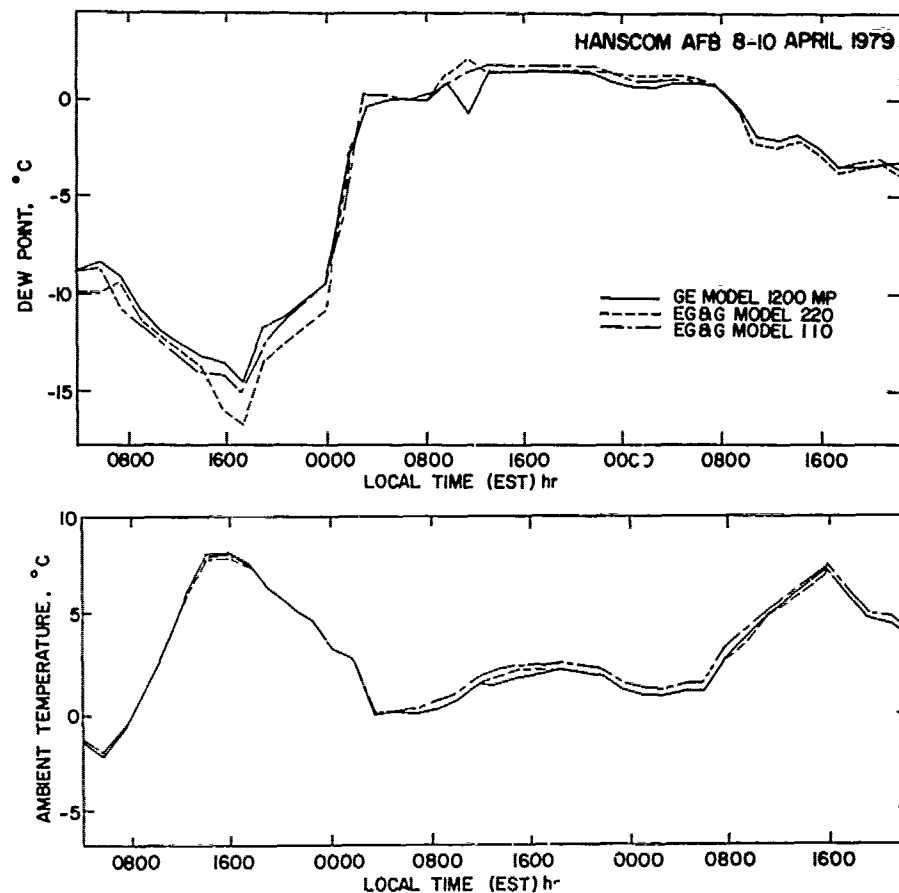


Figure 2. Comparison Field Tests of Three Temperature-Dew Point Systems

2.3 Recommendations

2.3.1 TEMPERATURE

Temperature sensors in any of the commercial and AWS inventoried dew-point hygrometers being considered in this program for use in a tactical automated weather station are acceptable and can be expected to meet operational requirements.

2.3.2 DEW POINT

(a) The AN/TMQ-20 is in active use within the AWS and can satisfy functional dew-point requirements. The complete system weights about 45 kg (100 lb), excluding case, which is a disadvantage for use in a tactical station. In addition, there

have been some suggestions that it be phased out of the inventory. However, as long as this instrument is the standard tactical dew point sensor, it will be given consideration as a candidate sensor.

(b) Preliminary testing of the EG&G 220 and the GE 1200MP suggests that either system could be an acceptable alternative to the AN/TMQ-20. Non-functional differences that relate to portability, ease of deployment, and serviceability will be important factors in a selection between these two instruments. More controlled field tests over a broad range of environmental conditions are being planned.

(c) The AN/TMQ-22 Meteorological Measuring Set was designed as a manual system and requires the nulling of a meter to obtain the temperature and dew point measurement. The system cannot be utilized without major redesign.

(d) The AN/TMQ-11, as previously noted, uses a lithium chloride resistance cell as the active sensing element. The system is heavy, approximately 100 kg. It requires careful attention for reliable operation and, compared to the optical dew point hygrometer, its range of operation is limited.

When all factors are considered, the optical dew point hygrometer system, particularly the newer commercially available sensors, are clearly instruments of first choice for use in a tactical automated weather station. These factors include cost, accuracy, range, size and weight, and maintenance considerations.

3. WINDS

Anemometers may be classified into the following major categories:

- (a) Momentum transfer-cups, vanes, and pressure plates,
- (b) Pressure on stationary sensor—pitot tubes and drag spheres,
- (c) Heat transfer—hot wires and hot films,
- (d) Doppler techniques—acoustic and laser,
- (e) Special methods—ion displacement, vortex shedding, and so on.

For use in a tactical weather station, the momentum transfer sensors (specifically the rotation types) currently constitute the most useful category of anemometers. Most of the other types have various limitations that can be related to factors of accuracy, range, complexity, cost, or maintainability. A survey of a number of currently available wind-measuring instrumentation has been made by Stone and Bradley.⁴ The survey provides information on principles of operation, specifications, and expected performance.

4. Stone, R.J., and Bradley, J.T. (1977) Survey of Anemometers, FAA-RD-77-49.

3.1 Requirements

The acquisition of reliable wind data is necessary for the generation of weather forecasts as well as for support of aircraft takeoffs and landings. The accuracy requirements of wind sensors for use in a tactical weather system are not particularly demanding. These sensors, however, have to perform over a wide range of environmental conditions, be rugged, and easily serviced. Design criteria recommended as FAA requirements by Stone and Bradley⁴ are listed in Table 2. These specifications would appear to be an adequate goal for a tactical weather station anemometer. The accuracies are consistent with recommended reporting procedures⁵ where wind speed is rounded to the nearest knot and wind direction to the nearest 10 degrees.

Table 2. Recommended Anemometer Specifications
(from Stone and Bradley)⁴

Wind Speed	
Range	0 to 65 m/sec (0 to 125 knots)
Threshold	1.3 m/sec (2.5 knots)
Accuracy	0 to 51.5 m/sec (0 to 100 knots): ± 0.51 m/sec (1 knot) or 5% whichever is greater
Distance Constant	51.5 to 65 m/sec (100 to 125 knots): ± 10% 20 m (66 ft)
Wind Direction	
Range	0 to 65 m/sec (0 to 125 knots)
Threshold	1.3 m/sec (2.5 knots)
Accuracy	± 10°
*Damping Ratio	0.2 to 0.3
*Damping Wavelength	6 to 12 m (20 to 40 ft)
**Distance Constant	20 m (66 ft)

* If vane

** If system is not a vane

5. Surface observations (1976) Federal Meteorological Handbook No. 1.

The reporting requirements for an automated weather station will probably be dictated by the local mission. The versatility of microprocessing technology will permit a wide range of data outputs tailored to specific requirements. Reporting options, for example, could include the following:

- (a) Variation of data averaging period,
- (b) Rounding-off of data,
- (c) Gusts,
- (d) Peak winds,
- (e) Fastest mile.

3.2 Equipment

3.2.1 INVENTORIED EQUIPMENT

Table 3 lists the wind-measuring sets currently in the AWS inventory along with accuracy specifications. These systems do not have convenient outputs which can be directly interfaced into an automated weather station without special signal conditioning. In the AN/TMQ-15, for example, the output for wind speed is pulses, the rate of which are proportional to the wind speed. Wind direction with this anemometer is determined by the time relationship produced by the relative positions of a rotating magnet and a series of fixed coils. Though these sensors would require some modification, no particular difficulties are anticipated.

The AN/GMQ-30 uses, essentially, the same sensors as in the AN/TMQ-15. In this system outputs can be transmitted over voice grade telephone lines and there is the capability for digital display of winds at a distance of up to 10 miles. The transmitter can also accommodate up to 10 indicators or recorders.

The AN/GMQ-11 wind-measuring set has a three-bladed propeller which is directed into the wind by a large vane. A tachometer magneto in the transmitter provides a dc output for the wind speed measuring. The wind direction circuit uses a synchro generator in the transmitter and a synchro motor in the indicator. Maintenance problems with this system led to the development of the AN/GMQ-20 by which it has been largely replaced. Both the AN/GMQ-11 and the AN/GMQ-20 transmitters have relatively large inertia or thresholds of operation.

Table 3. Specifications for AWS Anemometer Systems
(from AWS Pamphlet 105-53)³

AN/GMQ-11 (prop/vane)	AN/GMQ-20 (prop/vane)
Speed $\pm 1\%$ Direction: $\pm 2^\circ$	Speed: 3-40 knots (± 1.5 knots) 40-120 knots (± 3 knots) 120-240 knots ($\pm 10\%$) Direction $\pm 2^\circ$ Starting Speed (Transmitter) 3.4 knots Stopping Speed (Transmitter) 2.4 knots
AN/GMQ-30 (cup/ vane)	AN/TMQ-15 (cup/vane)
Speed ± 2 knots Direction $\pm 5^\circ$	Speed 0.75-50 knots (± 1.3 knots) 50-100 knots (± 2.0 knots) Direction $\pm 3^\circ$

3.2.2 COMMERCIAL EQUIPMENT

No attempt will be made to catalog the extensive body of commercially available wind sensors. Due to the desirability of having a sensor with no moving parts, state-of-the-art developments in hot wire and hot films, and ion displacement technology will continue to be closely followed.

3.3 Recommendations

Wind sensors in the AWS inventory can meet the immediate operational requirements for the tactical automated weather station. In addition to the obvious cost savings with their use, there would be distinct advantages in using proven systems that are extensively used within the AWS. Technicians in the field are familiar with their operation, repair, and maintenance. For these reasons, until a clearly superior instrument is available alternate commercial devices will not be sought.

Particular scrutiny will be given to the sensors of the AN/TMQ-15 (or AN/GMQ-30). A picture of the AN/TMQ-15 is shown in Figure 3. The costly components of the system, namely, the Wind Speed and Direction Indicator, and the Wind Data Converter can be entirely eliminated in an automated system. However, some modification of the sensors will be necessary. Modified units will be field tested and the data compared with that from other reference wind sets.

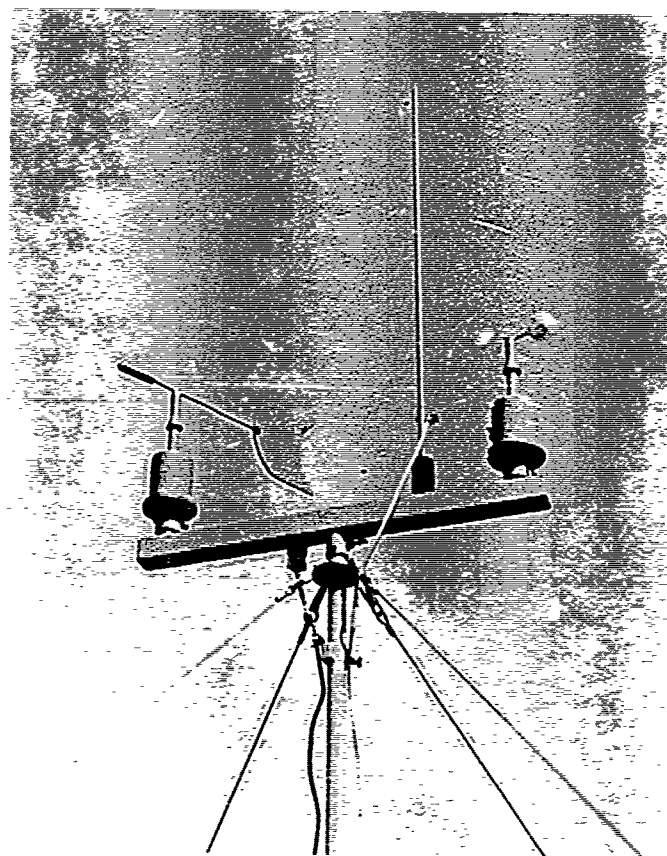


Figure 3. AN/TMQ-15 Wind Measuring Set

4. PRECIPITATION

The only precipitation gages in active use within the AWS are the ML-17 (Fixed), the ML-217 (Tactical), and a few smaller gages that are part of lightweight, hand held weather kits. Some of these gages, in normal field deployment, cannot be expected to provide the measurement accuracies ascribed to them. These gages are generally small glass or plastic cylinders with graduated markings for direct visual readout. They are not suitable for use in an automated weather station. The more readily automated precipitation instruments are the tipping bucket and weighing bucket types. These latter two types will be described briefly.

Tipping bucket rain gages are provided with a dual compartmented catch bucket calibrated to tip after a preset quantity of water has been accumulated. The design is such that each compartment is alternately filled and emptied. In currently available commercial gages each cycle is usually equivalent to 0.25 mm (0.01 in.) of rainfall; some instruments have been designed to tip in 0.13 mm (0.005 in.) steps. For some applications, as in maritime climates, where light rain or drizzle predominate these sensitivities may be inadequate. Another disadvantage exists in very heavy rain from spillage and from the fact that the tipping action cannot react in time to record the full rain amount. This underestimation is approximately proportional to the rate of rainfall and becomes important for rates in excess of 5 cm/hr (2 in./hr). Whatever disadvantages exist, they are offset by their general ruggedness, reliability, and relative sensitivity. In addition, with the use of thermostats and heaters, tipping buckets can be used during snowfall to record equivalent rainfall. Care is necessary in the design of heated buckets to ensure against clogging of the funnel by snow or the loss of precipitation by evaporation through excessive heating. Tipping buckets are usually provided with mercury contact switches which are activated during the tipping cycle.

In weighing bucket gages, the weight of water measured is directly related to accumulated rainfall. Weighing gages have the advantage of responding immediately to any precipitation entering the receiving bucket. Since they do not require the use of heaters during snowfall, as do the tipping bucket gages, evaporative loss is not a problem. During hot weather, however, accumulative rainfall measurements should account for evaporation; this would not be a problem in an automated system. Weighing bucket gages can be readily automated.

Two commercial tipping bucket gages will be examined for use in the tactical weather station, the Belfort Model 5-405HA and the Weather Measure Corp. Model P511-E. The Belfort gage was selected since it is manufactured to NWS specifications and is widely used. The Weather Measure gage was selected as it has received considerable attention by other government agencies for possible use in other automated weather systems. Both gages are calibrated in 0.25 mm (0.05 in.) increments and have similar functional specifications. A Belfort weighing gage, Series No. 5915, will also be purchased for field evaluation and intercomparison with the tipping bucket gages. Of prime concern in these field tests will be sensor reliability, ease of maintenance, and operation over a wide range of environmental extremes.

5. PRESSURE

Atmospheric pressure monitoring devices, in general, use an elastic element as the transducer. These elements take many forms, such as the bourdon tube, diaphragm, bellows, dead-weight piston, or piezoelectric crystal. The output can be provided as either a direct mechanical readout or as an electrical signal. Examples of the direct mechanical pressure sensors include the mercurial barometer and many aneroid capsule sensors with gear or linkage actuated pointers. The electrical transducers have circuits that provide related changes in either capacitance, resistance, reluctance, or inductance.

5.1 General Requirements

For use in a tactical automated weather station a barometer should have, as a minimum, the accuracy of the standard military aneroid sensors. For the ML-331/TM, ML-332/TM, and ML-333/TM series this accuracy is ± 0.35 mb (± 0.035 kPa). Also, an instrument without gears, linkages, or other moving parts would be preferred. Obviously, such a sensor would be easier to maintain and, having fewer wearing surfaces, would tend to hold its calibration more readily.

The selection of a barometer for the tactical weather observation station will depend upon its application. If the sensor is to be used for setting aircraft altimeters, specifications will be stringent, as will requirements for calibration validation and maintenance. If the sensor is to be used for weather forecasting, standards can be somewhat relaxed. However, it should still be possible to provide "estimated" altimeter settings in the latter situation.

A wide variety of readout options would be available regardless of the sensor selected. With the use of microprocessors and microcomputers it is envisioned that a number of options would be available to the user. These could include:

- (a) Rapidly rising or falling pressure,
- (b) Pressure jumps,
- (c) Station pressure,
- (d) Altimeter setting,
- (e) Indication that pressure is only "estimated" when winds are high or gusty.

5.2 Equipment

5.2.1 INVENTORIED EQUIPMENT

Barometers currently in use in support of Air Force and Army operations are listed in Table 4 along with pertinent characteristics and their primary use.

Table 4. AWS Inventoried Barometers

Nomenclature	Type	Range, mb (kPa)	Accuracy mb (kPa)	Primary Use
ML-102G, Barometer	Aneroid	745-1065 (74.5-106.5)	± 0.3 (± 0.03)	Permanent or tactical stations
ML-330/FM, Barometer	Fortin	725-1060 (72.5-106)	± 0.025 (± 0.0025)	Precision barometer used by field maintenance shops
ML-331/TM, ML-332/TM, and ML-333/TM, Barometer	Aneroid	ML-331, 840-1040 (84-104) ML-332, 745-1040 (74.5-104) ML-333, 540-1030 (54-103)	± 0.35 (± 0.035) " " " "	Precision portable barometers used by field maintenance shops
ML-434/PM, Barometer	Aneroid	750-1050 (75-105)	± 0.5 (± 0.05)	Part of AN/PMQ-4 Manual Meteorological Station; for field use
ML-459/PMQ-1, Barometer	Aneroid	750-1050 (75-105)	± 0.5 (± 0.05)	Part of AN/PMQ-1 Meteorological Station, Manual; for field use
ML-512GM, Mercurial	Fortin	735-1060 (73.5-106)	± 0.002 (± 0.0002)	Permanent indoor installations
MI-563/UM, Barograph	Aneroid	796-1050 (79.6-105)		Recording barometer for characterization of pressure tendency

Field station weather barometers in the AWS inventory are either Fortin type mercurials or the more portable direct-reading aneroid capsule instruments. Both of these instrument types require an observer to obtain the measurements. Since they are not readily automated they will not be given further consideration for use in a tactical weather station.

5.2.2 COMMERCIAL EQUIPMENT

The characteristics of some commercially available pressure sensors that have potential application to a tactical weather station may be found in Table A2 of Appendix A. Though this table should not be construed as complete, it includes instruments typical of several different type and covers a range of prices between \$300 to over \$8000. The majority of these instruments are under \$1000 and use an aneroid capsule as the active element and have a capacitive readout.

Some of these sensors will experience degraded accuracy when operated at extreme outside air temperatures. This limitation would not be a factor for an instrument sheltered within a heated facility. Pressure sensors will be considered only for use within a heated shelter.

No difficulty would be anticipated in incorporating most of these devices into an automated system.

5.3 Recommendations

Due to the difficulty of automating any of the inventoried AWS barometers, attention will be directed toward commercially available instrumentation. It is anticipated that several of the sensors listed in Table A2 will be evaluated in an intercomparison field test. The Mensor Corp. Model 10100-001 and the Sperry Flight System Model DASI will be available and can serve both as candidate and as secondary standards for this study.

6. VISIBILITY

6.1 General

Visibility is defined in the U.S. "as the greatest distance in a given direction at which it is just possible to see and identify with the unaided eye (a) in the daytime, a prominent dark object against the sky at the horizon, and (b) at night, a known, preferably unfocused, moderately intense light source".⁶ There are two specific visibility determinations that are of particular interest to Air Force operations. One is prevailing visibility (PV) which is based on an observer's estimation of visibility and which is used primarily for weather forecasting purposes. The other is

6. Huschke, R. E., Editor (1959) Glossary of Meteorology, American Meteorological Society, Boston, Massachusetts.

runway visual range (RVR) which is a highly specialized determination of visibility used for aviation operations.

Prevailing visibility is defined "as the greatest horizontal visibility prevailing throughout at least half of the horizon circle which need not necessarily be continuous".⁵ Currently available visibility meters determine a local or point visibility which if used singularly, is not an operational equivalent to PV. Several groups, including the Air Force, are trying to develop an algorithm, using spatially separated visibility instruments, that could be used operationally to automate the PV observation.

RVR is an instrumentally determined visibility. There is international agreement on its meaning and operational RVR systems have been in use for a number of years. RVR is defined "as the maximum distance in the direction of take-off or landing at which the runway, or the specified lights or markers delineating it, can be seen from a position above a specified point on its line at a height corresponding to the average eye-level of pilots at touchdown. In the U.S., RVR is a value determined normally by instruments located alongside, and about 14 ft higher than, the center line of the runway and calibrated with reference to the sighting of high intensity runway lights or the visual contrast of other targets—whichever yields the greater visual range".⁵ The visibility sensors examined in this study were considered only as to their potential as RVR sensors. The ancillary items that are required as part of an RVR system such as a day/night sensor or a processor are not considered in the present study.

6.2 Requirements

A reasonable requirement for any visibility sensor is that it provides accurate and timely information on the atmospheric extinction over a range that is compatible with the current RVR sensor (namely, the transmissometer). The transmissometer provides a measurement of extinction from which the RVR can be determined over a range of 500 to 6000 ft (150 to 1800 m), once a minute. The accuracy of the visibility determination is dependent on the baseline of the transmissometer and varies from a fraction of a percent to more than 20 percent. An RVR range of 500 to 6000 ft corresponds to an extinction range of $2.2 \times 10^{-2} \text{ ft}^{-1}$ (600-ft RVR, night, runway edgelight setting 5) to $5.0 \times 10^{-4} \text{ ft}^{-1}$ (6000-ft RVR, day, threshold contrast 0.05).

6.3 Equipment

A large number of instruments using various measuring techniques have been developed for the determination of visibility.⁷ The transmissometer which

7. Middleton, W. E. K. (1952) Vision Through the Atmosphere. University of Toronto Press, Canada.

measures the transmittance of a sample volume along its baseline is the most commonly used recording visibility meter. It belongs to the class of instruments defined as extinction meters. Recently, there has been a significant number of scatter measuring instruments developed for the purpose of determining visibility.

6.3.1 INVENTORIED EQUIPMENT

In the U.S., the Douglas-Young transmissometer is used by both the military and civil sector to determine visibility. The instrument is configured to measure transmittance over a 250- or 500-ft baseline. It was developed and put into operation as a visibility meter over 35 years ago.⁸ In the 60's, the transmissometer was used as the basis for RVR system deployed in the United States. Generally, the instrument has performed satisfactorily. Its major drawbacks are

- (1) Alignment is critical and difficult to maintain, and
- (2) There is no satisfactory means to calibrate the instrument when the visibility is less than 5 km (3 miles).

The instrument shown in Figure 4 is the receiver of a Douglas-Young type transmissometer and is one of the many meteorological instruments installed at the AFGL Weather Test Facility (WTF), Otis AFB, Massachusetts.

The Air Force is currently upgrading its version of the transmissometer, AN/GMQ-10.⁹ Only the housings and the projector lamp of the original system will be retained; its new designation is AN/GMQ-32, Transmissometer Set. Testing of the new solid state version shows it to be superior to the older model; it has improved performance and requires little maintenance. Its performance would be adequate for bare base operations; however, because of its size and extensive installation requirements, it is not an acceptable candidate sensor. Other currently available transmissometers are unacceptable for the same reasons.

6.3.2 COMMERCIAL EQUIPMENT

A number of domestic and foreign visibility meters that measure atmospheric scattering have been developed recently. It is convenient to categorize these instruments by the type of atmospheric scattering that they measure, that is, (1) total scatter, (2) forward scatter, or (3) back scatter. Use of these instruments assumes that they provide an accurate indication of total atmospheric scattering and that any absorption by the attenuating medium is negligible. Test results show that scatter meters do indeed provide a reasonable and useful indication of atmospheric extinction when visual obscuration is caused by fog. However,

8. Douglas, C. A., and Young, L. L. (1945) Development of a Transmissometer for Determining Visual Range, NBS Technical Development Report No. 47.

9. Snell, M. R., Capt (1979) Final Report of Operational Testing of the Transmissometer Set AN/GMQ-32 at Travis AFB, CA and Mather AFB, CA.

in precipitation, particularly in snow, their performance and calibration vary according to the type of scattering measured and/or to instrument design features, in particular to the size of the sampling volume.

A number of the following scatter measuring meters have been used at both the AFGL/WTF, Otis AFB, Massachusetts and the AFGL Mesonet at Hanscom AFB, Bedford, Massachusetts as part of an ongoing meteorological research and development program. Characteristics of these instruments are listed in Table 5.

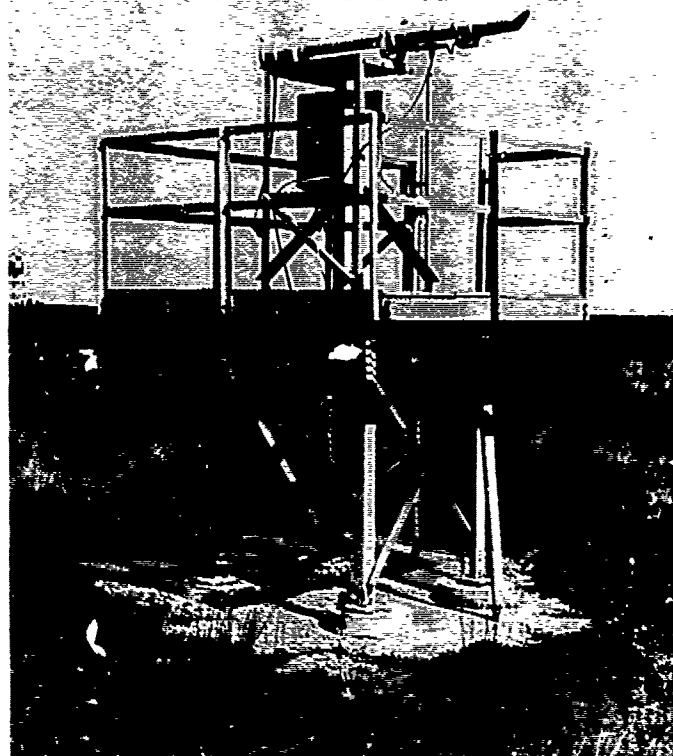


Figure 4. AN/GMQ-10 Transmissometer Receiver

Table 5. Characteristics of Visibility Sensors

Instrument	FUMOSSENS III	Fog Visiometer	Forward Scatter Meter	* Modified Forward Scatter Meter	Videograph
Manufacturer	IMPULSPHYSIK, GmbH Hamburg, Germany	MRI, Inc., Altadena, CA	EG&G Environmental Equipment Division Waltham, MA	Wright & Wright, Inc., Oak Bluffs, MA	IMPULSPHYSIK, GmbH
Measurement Technique	Forward Scatter	"Total" Scatter	Forward Scatter	Forward Scatter	Back Scatter
Measurement Volume	Conical 50 cm long	Conical 35 cm long	Toroidal 500 cm ³	Toroidal 450 cm ³	3 m to 200 m in front of device
Light Source	Xenon flash lamp	Xenon flash lamp	Quartz halogen lamp	Quartz halogen lamp	Xenon flash lamp
Modulation Frequency	10 Hz	2 Hz	292 Hz	Not finalized	3 Hz
Extinction Measurement Range	** $3 \times 10^{-4} \text{ m}^{-1}$ to $3 \times 10^{-2} \text{ m}^{-1}$	** $6 \times 10^{-4} \text{ m}^{-1}$ to $6 \times 10^{-2} \text{ m}^{-1}$	$5 \times 10^{-4} \text{ m}^{-1}$ to $5 \times 10^{-2} \text{ m}^{-1}$	$1.6 \times 10^{-4} \text{ m}^{-1}$ to $5 \times 10^{-2} \text{ m}^{-1}$	$5 \times 10^{-4} \text{ m}^{-1}$ to $1.5 \times 10^{-2} \text{ m}^{-1}$
Weight	30 kg	20 kg	60 kg	22 kg	60 kg

*These are tentative specifications

** Available with different ranges

6.3.2.1 Videograph

The Videograph is a backscatter measuring meter manufactured by Impulsphysik, GmbH, Hamburg, West Germany. The instrument, shown in Figure 5, consists of a projector inclined upward at an angle of 3.5° and a receiver mounted above the projector in a common housing. The light source is a short duration ($1 \mu\text{sec}$) xenon flash lamp which is pulsed at a 3 Hz rate. There is no compensation for light source variations. However, the manufacturer states that the flash lamp output is extremely stable, not affected by ambient temperature and power supply variations, and needs adjustment only once a year to compensate for lamp aging. The receiver uses a photodiode detector. The common projector/receiver sampling volume is relatively large when compared to most scatter measuring meters but is significantly smaller than sampling volumes of most transmissometers. The instrument provides a 0 to 1 mA analog dc output which should be satisfactory for automated operation.

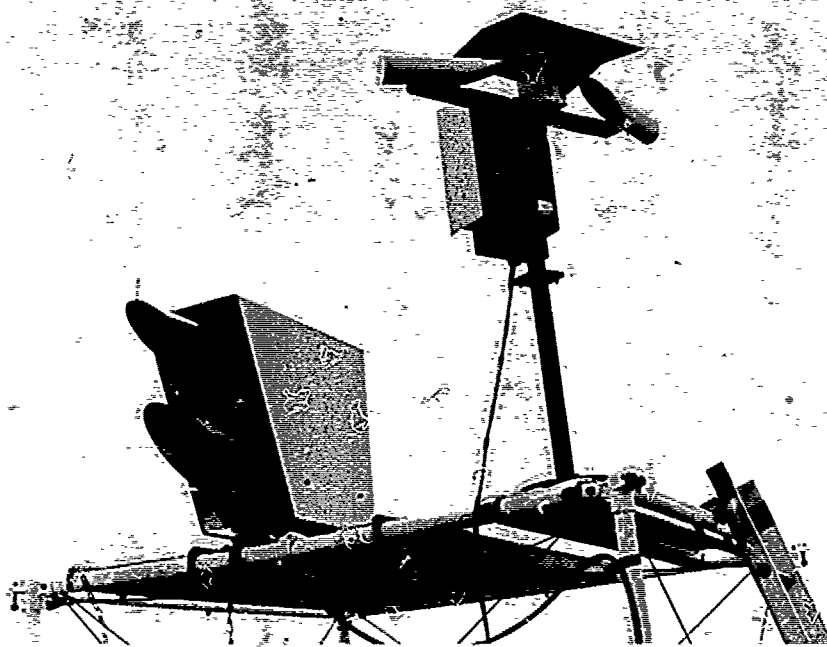


Figure 5. Impulsphysik Videograph and Fumosens II

The Videograph is being used in the U. S. as the visibility sensor at seven NWS AUTOB stations and, in a simpler version, as a fog detector at automated Coast Guard stations.

The instrument has been tested extensively by various groups, including the (a) Meteorological Institute, University of Berlin, West Germany,¹⁰ (b) NOAA/NWS, Sterling, Virginia,¹¹ (c) AFGL, Hanscom AFB, Massachusetts,¹² and (d) Atmospheric Environment Service (AES), Downsview, Ontario, Canada.¹³

It is concluded from reported test results and operational experience gained with the instrument in the field that:

(a) The instrument provides consistent results when its output is compared to human observations and to the transmissometer. However its calibration depends on the scattering medium. Therefore, for optimum operation, the weather condition will have to be identified in order to apply the correct calibration curve. Otherwise, a combined calibration curve would have to be used with less accurate results.

(b) The instrument operates reliably with reasonable maintenance requirements.

(c) Routine calibration methods and devices, available from the manufacturer, are not adequate. A calibration device recently devised by the Canadian AES may provide a means for the routine field calibration of the instrument.

(d) Installation requirements are not extensive. It is relatively large and heavy, (60 kg). Therefore, it may be difficult to deploy a Videograph in a bare-base situation.

6.3.2.2 Fog Visiometer

The Fog Visiometer is a "total" scatter measuring meter manufactured by Meteorology Research, Inc., Altadena, California. The instrument is shown in Figure 6. It consists of a xenon flash lamp, a photomultiplier detector, a light trap and associated circuitry all of which are mounted on a single rail. The flash lamp illuminates the sampling volume through an opal glass diffuser; the lamp is pulsed at a 2 Hz rate. An internal automatic gain control system is provided to compensate for flash lamp aging and for soiling of the opal glass diffuser. The photomultiplier detects the scattered flash lamp energy from the sampling volumes

10. Vogt, H. (1968) Visibility measurement using backscattered light, JAS 25:912-918.
11. Observation Techniques Development and Test Branch (1973) Videograph Calibration, Lag Rpt No. 4-73, Task No. 2159-10-31.
12. Chisholm, D. A., and Jacobs, L. P. (1975) An Evaluation of Scattering-Type Visibility Instruments, AFCRL-TR-75-0411, AD B010224L.
13. Sheppard, B. E. (1978) Calibration of Scattering Functions Visibility Sensors at Toronto International Airport March 1973 to December 1975, TR4 Dec 78.

throughout an angular range of 7° to 170° . The sampling volume is small. The instrument provides a 0 to 5 V analog dc output which should be satisfactory for automated operation.

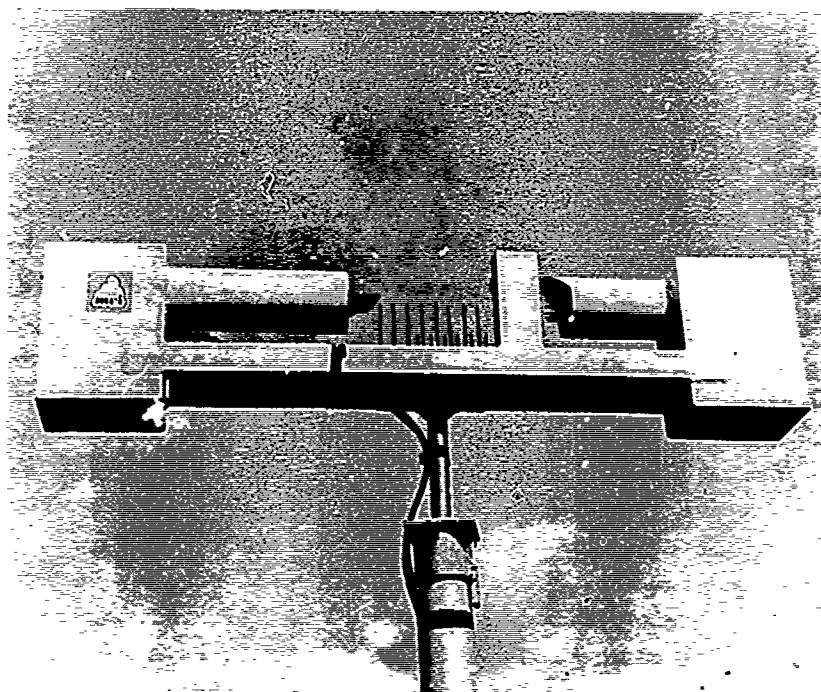


Figure 6. MRI Fog Visiometer

The Fog Visiometer has been examined by a number of groups including the California Division of Highways,¹⁴ AFGL, Hanscom AFB, Massachusetts,¹² and AES, Downsview, Ontario, Canada.¹³ It is concluded that:

(a) The instrument appears to provide good information when operating in fog. It correlates well with other sensors and human observations. The California Division of Highways concluded that of all the devices they examined, the Visiometer showed the most promise because of its greater range of measurement in dense fog. However, in rain and snow the correlation of its output to that of other sensors and

14. Bemis, G. R., Pinkerman, K. O., Shirley, E. C., and Skog, J. B. (1973) Detectors for Automatic Fog-Warning Signs, California Division of Highways, CA-DOT-TL-7121-1-73-22.

human observations is low. This may be attributed to a less uniform distribution of scatterer size in precipitation and to its small sampling volume. During the AFGL tests in snow, it was reported that snowflakes would collect at the light trap, altering the reflective characteristics of the light trap.

(b) The instrument operates reliably with reasonable maintenance requirements.

(c) Means are provided to routinely calibrate the device.

(d) Installation requirements are not extensive. It weights 20 kg. Therefore, it would be relatively easy to deploy a Fog Visiometer in a bare-base situation.

6.3.2.3 Forward Scatter Meter (FSM)

The FSM was developed for AFGL by EG&G International, Inc., Environmental Equipment Division, Waltham, Massachusetts. The instrument is shown in Figure 7. It is constructed as an integral unit consisting of a projector and receiver mounted at the ends of two inclined arms. The arms join at a mounting column to which the control box is also attached. The light source is a halogen quartz lamp whose output is chopped at a rate of 292 Hz. Compensation for variations in light source intensity is provided. The toroidal shaped sampling volume is approximately 0.05 m^3 (1.7 ft^3). The instrument provides a 0 to 5 V analog dc linear output which should be satisfactory for automated operation. An optional 0-5 dc logarithmic output (logarithm of the linear output) is available.

The instrument has been tested extensively at AFGL under a variety of conditions.^{12, 15, 16, 17} The Canadian AES has tested the FSM¹³ and compared its output to human observations and the Videograph. The FMS has been used as the visibility sensor in slant range visibility experiments conducted at the FAA National Aircraft Facility Experimental Center, New Jersey¹⁸ and at the AFGL/WTG, Otis AFB, Massachusetts.^{19, 20}

15. Hering, W.S., Muench, H.S., and Brown, H.A. (1971) Field Test of Forward Scatter Visibility Meter, AFCRL-TR-71-0315, AD 726995.
16. Muench, H.S., Moroz, E.Y., and Jacobs, L.P. (1974) Development and Calibration of the Forward Scatter Visibility Meter, AFCRL-TR-74-0145, AD 783270.
17. Muench, H.S., and Brown, H.A. (1977) Measurement of Visibility and Radar Reflectivity During Snowstorms in the AFGL Mesonet, AFGL-TR-77-0148 AD A049258.
18. Slant Visual Range (SVR)/Approach Light Contact Height (ALCH) Measurement System: Evaluation in Fog: January 1974, Final Report Phase II, FAA-RD-74-7.
19. Hering, W.S., and Geisler, E.B., Capt (1978) Forward Scatter Meter Measurements of Slant Visual Range, AFGL-TR-78-0191, AD A064429.
20. Geisler, E.B., Capt (1979) Development and Evaluation of a Tower Slant Visual Range System, AFGL-TR-79-0209, AD A082384.



Figure 7. EG&G Forward Scatter Meter and Impulsphysik Fumosens III

It is concluded from reported test results and operational experience gained with the instrument in the field that;

(a) It provides reliable and accurate measurements of atmospheric extinction coefficient at a point location during all kinds of restrictions. Its output is highly correlated to human observations and transmissometer data.

(b) The instrument operates reliably and has reasonable maintenance requirements.

(c) There are two devices available for calibrating the meter. A laboratory calibrator provides the means to perform a basic calibration of the FSM, whereas, proper operating characteristics of the meter can be determined with a field calibrator. Both devices are relatively large. Though the laboratory calibrator has been used in the field, it is difficult to handle in windy conditions.

(d) Installation requirements are not extensive. It weighs 61 kg. Its center of gravity is out in space, therefore, it is very awkward to carry and it may be difficult to deploy in a bare-base situation.

6.3.2.4 Current Developments

6.3.2.4.1 (Fumosens III)

The Fumosens III, shown in Figure 7, is a forward scatter measuring meter manufactured by Impulsphysik, GmbH, Hamburg, West Germany. It is an upgraded model of their highway fog detector. The instrument has been obtained on a rental basis for evaluation at the AFGL/WTF.

6.3.2.4.2 (Modified FSM)

Wright and Wright, Inc., Oak Bluffs, Massachusetts, under contract to AFGL, is modifying the FSM to improve its operating characteristics and its transportability. Preliminary testing of the modified instrument is scheduled to begin in late summer of 1980.

6.3.3 LIDAR

The possibility of using lidar as a sensor for determining atmospheric extinction has been investigated by a number of experimenters since the mid-60's. Its feasibility has been demonstrated using a variety of techniques and equipments.²¹ However, none of the systems fabricated to date show operational potential. Currently, there are only two active lidar visibility programs in the U.S.

The Army's Atmospheric Sciences Laboratory has developed the "visioceilometer" which is an extensively modified AN/GVS-5 Laser Rangefinder. Visibility is determined from the backscattered signal using the "slope" technique.²² Preliminary tests with the experimental prototype model, XE-1, were conducted at the AFGL/WTF, Otis AFB.²³

Raytheon Co. was contracted with to fabricate a developmental lidar system for AFGL. The objective of the development was to implement a novel "analog zone" technique for determining atmospheric transmission as proposed by HSS, Inc.²⁴ Raytheon was unable to provide an operable laser, and as a result, the technique

21. Moroz, E. Y. (1980) Lidar visibility measurements, Light Scattering by Irregularity Shaped Particles: 35-38, Plenum Press, New York
22. Viezee, W., Oblanas, J., and Collis, R. T. H. (1973) Evaluation of the Lidar Technique of Determining Slant Range Visibility for Aircraft Landing Operations, Final Report - Part II AFCRL-TR-73-0708, AD 776054.
23. Bonner, R. S., and Lentz, W. J. (1979) The Visioceilometer: A Portable Cloud Height and Visibility Indicator, ASL-TR-0042.
24. Stewart, H. S., Shuler, M. P., Jr., and Brouwer, W. (1976) Single Ended Transmissometer Using the Analog Zone Principle, HSS-TD-043.

has not been demonstrated. Work on the system is continuing in-house at AFGL. Progress on the above efforts will be followed closely for possible future bare-base application.

6.4 Recommendations

The investigation has shown that there are scatter measuring meters available that can be used for determining RVR at bare-base airfields. These meters, as well as new meters that show potential, will be examined and tested further in order to determine the most suitable candidate sensor for automated tactical bare-base operations. Also, other items, such as day/night sensor and processing required for the determination of RVR, will be investigated.

7. CLOUD HEIGHT

7.1 General

The measurement of cloud height is required at tactical airfields for the determination of ceilings. The range measurement requirement for tactical ceiling measuring equipment is from the surface to 3000 ft (910 m) with a resolution of 50 ft (15 m) and a threshold of 50 ft (15 m). A desirable measurement range is from the surface to 10,000 ft (3040 m).^{*} This information is used by pilots for aircraft guidance and also by forecasters for weather prediction.

7.2 Status of Cloud Height Measurement

There are a number of operational methods listed in the FMH No. 1⁵ for obtaining cloud height.

(a) The majority of these methods are based on human observations. These include pilot reports, balloon or ceiling light observations, and observer estimations. Since these methods do not lend themselves to automation, they have not been considered as possible candidates.

(b) A vertically pointing microwave cloud height radar is one of two instrumental techniques listed in the handbook, for obtaining cloud height. The transit time of the microwave pulse, from the radar to the cloud and back, is measured and related to cloud height. Recently, these radars (AN/TPQ-11) were removed from the inventory because the cost to maintain them was very high.

^{*} AWS letter to AFGL/CC, 10 September 1979.

(c) Figure 8 illustrates the most commonly used for measuring cloud height; the standard Rotating Beam Cloud Height Measuring Set (AN/GMQ-13) projector is on the right and the tactical Cloud Height Set (AN/TMQ-14) projector on the left. In these devices a light beam from a tungsten lamp is projected in a rotating or oscillatory fashion over a vertically looking detector. When the light beam intersects a cloud, a portion of the light is reflected toward the detector. The height of the cloud can be determined by triangulation. Neither the AN/GMQ-13 nor the AN/TMQ-14 is a suitable sensor for automated cloud height measurement in a tactical environment. The size of and installation requirements for the RBC preclude its use. The three measurement range options of the AN/TMQ-14 are limited and the instrument is considered obsolete and logistically unsupportable for tactical airfield operations by AWS.*

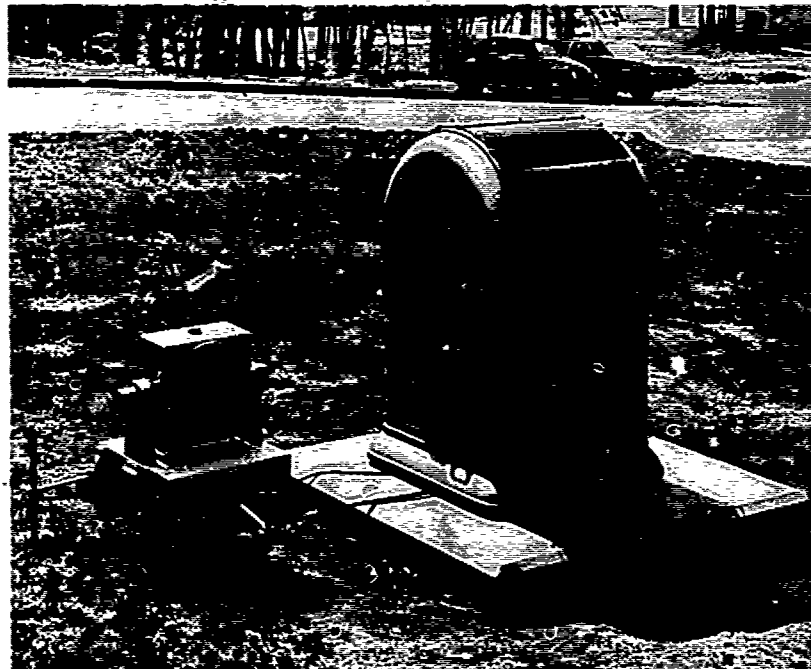


Figure 8. AN/TMQ-14 Tactical Cloud Height Projector and AN/GMQ-13 Cloud Height Projector

*AWS Letter to AFGL/CC, 10 September 1979)

7.3 Current Developments

7.3.1 LASER CEILOMETERS

A number of investigators have examined the use of optical radars (lidars) for determining cloud height. The acronym "lidar", light detection and ranging is attributed to Ligda. As early as 1963, Lidga and his associates at Stanford Research Institute²⁵ used a giant pulse ruby laser to detect a variety of atmospheric phenomena including clouds. In 1968,²⁶ comparative measurements of cloud height using a ruby laser rangefinder and an RBC yielded a high correlation but large bias between comparative readings. A later evaluation of the lidar and RBC measuring techniques in which "simultaneous" measurements of cloud height were obtained,^{27, 28} showed that comparative measurements were highly correlated and the measurements obtained using the two techniques were systematically different. However, the difference was not operationally significant. It was concluded that lidar is potentially a superior cloud height measuring technique. It was also noted that it was difficult to assure proper optical alignment of the RBC and that the large measurement differences obtained in earlier experiments may have been caused by poor alignment of the RBC.

A variety of lasers have been used to measure cloud height using ruby, erbium, neodymium and gallium arsenide (GaAs) sources. There have been extensive but unsuccessful efforts in the U.S. to develop an operational system. Undoubtedly, the requirement that any laser intended for use out-of-doors in an unattended mode must present no eye hazard, greatly increases the engineering difficulty of fabricating a laser ceilometer.

Current programs in the U.S. which may result in a suitable laser cloud height sensor for tactical base operations include the following:

(a) The Federal Aviation Agency (FAA) has contracts with both Hughes Laser Systems Division and Sanders Associates, Inc. to develop an eyesafe laser ceilometer capable of measuring from 300 to 3000 meters (100 to 10,000 ft) for use at major civil airfields.

25. Ligda, M.G.H. (1965) The laser in meteorology, Discovery, July 1965.
26. Fuller, W.H. (1968) Cloud Height Measurements Using a Laser Range Finder, Internal Report NASA Langley Research Center, VA.
27. Moroz, E.Y., Lawrance, C.L., and Travers, G.A. (1973) Laser Ceilometers, AFCRL-TR-73-0751, AD 777201.
28. Moroz, E.Y., and Travers, G.A. (1975) Measurement of Cloud Height, AFCRL-TR-75-0306, AD A015737.

(b) The National Weather System (NWS) is evaluating a GaAs laser ceilometer as a candidate cloud height sensor for the Automated Low Cost Weather Observing System (ALWOS). The system was obtained under contract to Impulsphysics, U.S.A. and is designed to measuring from 30 to 900 meters (100 to 3000 ft).

(c) T.W. Giff Co., Inc. is developing an inexpensive GaAs laser ceilometer capable of measuring cloud height from 15 to 3000 meters (from 50 to 10,000 ft). Positive results were obtained in recent tests of an experimental model at the NWS Gramex Building, Silver Springs, Maryland.²⁹ The developer is currently designing a preproduction model.

(d) The Army's Atmospheric Science Laboratory is developing a portable visibility and cloud height measuring device, the "visio-ceilometer". The XE-2 model which will have a built-in transient recorder and microprocessor, is being designed to measure cloud height from 30 to 3000 meters (100 to 10,000 ft). Its neodymium laser source is not eyesafe which could prevent its use at tactical airfields.

7.3.2 RADAR CEILOMETERS

Ford Aerospace & Communications Corp. has been exploring the possibility of developing a low-power microwave radar cloud height measuring set using a solid-state microwave source and modern signal processing. Functionally, the set would be similar to the defunct AN/TPQ-11 cloud height radar. The new radar would be able to detect cloud bases and tops, multi-layer clouds, and clouds in rain and snow. As presently envisioned, it would have a 6-ft diameter antenna, a 0.13 m³ pedestal and weigh 230 kg. Except for its size, weight, and possible high cost, an operational version of such a radar would certainly be an attractive candidate cloud height sensor.

7.4 Recommendations

At the present time, there is no satisfactory cloud height sensor available for use at tactical airfields. It is planned to closely monitor current developments in lidar and radar ceilometry. As sensors become available, their potential for use in automated tactical base-base operations will be examined. As funds permit, likely candidates will be obtained for test and evaluation.

29. Vertical Beam Ceilometer Progress Report (1980) T.H. Giff Co., Inc., Anaheim, CA.

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1. Wexler, A. (1970) Measurement of humidity in the free atmosphere near the surface of the earth, AMS Meteorological Monograph, Vol. II (No. 33):262-282.
2. Weiss, B. D. (1968) Error Analysis of the Humidity-Temperature Measuring Set, AN/TMQ-15, AFCRL-TR-68-0154, AD 669095.
3. Air Weather Service meteorological sensors and related equipment, AWS Pamphlet 105-53, September 1978.
4. Stone, R. J., and Bradley, J. T. (1977) Survey of Anemometers, FAA-RD-77-49.
5. Surface observations (1976) Federal Meteorological Handbook No. 1.
6. Huschke, R. E., Editor (1959) Glossary of Meteorology, American Meteorological Society, Boston, Massachusetts.
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Appendix A

Table A1. Temperature-Dew Point Hygrometer Characteristics for EG&G Model 220 and General Eastern Model 1200MP

A. EG&G, Inc., Waltham, Massachusetts, Model 220 Dew point and Temperature Monitoring System	
<u>Temperature</u>	
Range:	-50°C to +50°C
Accuracy:	± 0.4°C over full range
Response:	40 sec time constant
Sensor type:	Thermistor
<u>Dew Point</u>	
Range:	-50°C to +50°C
Depression:	45°C minimum
Accuracy:	± 0.4°C nominal
Depression Slew Rate:	2°C per sec maximum
Sensitivity:	± 0.06°C
<u>Operating Temperature</u>	
-50°C to +50°C	
<u>Electrical</u>	
<u>Outputs:</u>	Simultaneous temperature and dew point; 0-10 VDC over full range.
Balancing:	Automatic, electronic, self-standardization at 6, 12, or 24 hr
B. General Eastern, Corp., Watertown, Massachusetts, Model 1200MP Meteorological Dew Point and Temperature System	
<u>Temperature</u>	
Range:	+50°C to -75°C
Accuracy:	± 0.2°C
Response:	± 1°C/min typical
Sensor Type:	Platinum resistance thermometer
<u>Dew Point</u>	
Range:	+50°C to -75°C
Depression:	65°C maximum
Accuracy:	Between dew points of +50°C and -20°C, ± 0.2°C. Between frost points of -20°C and -75°C, errors increase from ± 0.2°C at -20°C to ± 1°C at -75°C
Response:	Dew point sensing mirror is capable of heating or cooling at a rate of 2°C per sec, at temperatures above 0°F

Table A2. Comparison of Selected Commercially Available Pressure Sensors

Bell & Howell Pasadena, California Model 4-461	
Principle: Range: Static Accuracy: Temperature Effect: Temperature Range: Electrical Data:	Capacitive pressure sensing capsule 896-1068 mb (89.6-106.8 kPa) $\pm 0.032\%$ of reading $\pm 0.002\%/^{\circ}\text{C}$ 40° to 100°F (4° to 38°C) Input 110 VAC Output TTL BCD
Computer Instruments Corp. Hempstead, New York Model 8600	
Principle: Range: Static Accuracy: Temperature Effect: Temperature Range: Electrical Data:	Capsule with linear variable differential transformer (LDVT) output 800-1034 mb (80-103.4 kPa) $\pm 0.1\%$ F.S. $\pm 0.005\%$ span/ $^{\circ}\text{C}$ -55° to +71°C Input $\pm 15, +28$ VDC Output 0-10 VDC
Data Instruments Inc. Lexington, Massachusetts Model AB	
Principle: Static Accuracy: Temperature Effect: Temperature Range: Electrical Data:	Semiconductor-piezoresistive $\pm 0.5\%$ F.S. 1%/100°F (1%/55°C) 30° to 130°F (-1 to 54°C) Input 5 VDC or AC Output 0-100 mv
Mensor Corp. Houston, Texas Model 10100-001	
Principle: Range: Accuracy: Temperature Range: Electrical Data:	Quartz bourdon tube with electro-optical output 0-15 psi (0-103 kPa) $\pm 0.01\%$ of reading 20° to 30°C Input 115 VAC Output 0-10 mv BCD or binary

Table A2. Comparison of Selected Commercially Available Pressure Sensors
(Cont)

MKS Instruments Corp. Burlington, Massachusetts Model 220A	
Principle:	Capacitive pressure sensor capsule
Range:	800-1034 mb (80-103.4 kPa)
Accuracy:	$\pm 0.25\%$ of reading + temperature effects
Temperature Effects:	Zero ± 3 parts in 10,000/ $^{\circ}\text{C}$ Span ± 6 parts in 10,000/ $^{\circ}\text{C}$ F. S.
Temperature Range:	0-130 $^{\circ}\text{F}$ (-18 to 54 $^{\circ}\text{C}$)
Electrical Data:	Input 15, 230, 24 VDC Output 0-10 VDC
Rosemont, Inc. Minneapolis, Minnesota Model 1201F1	
Principle:	Capacitive pressure sensing capsule
Range:	800-1100 mb (80-110 kPa)
Static accuracy:	$\pm 0.1\%$ F. S.
Operating accuracy:	$\pm 0.3\%$ F. S. over temp range
Temperature Effect:	$\pm 0.25\%$ FSP
Temperature Range:	-55 $^{\circ}\text{C}$ to +71 $^{\circ}\text{C}$
Electrical Data:	Input ± 15 or ± 28 VDC Output 0-5 or 0-10 VDC
Rosemont, Inc. Minneapolis, Minnesota Model 1332A	
Principle:	Capacitive pressure sensing capsule
Range:	745 to 1083 mb (74.5 to 108.3 kPa)
Static Accuracy:	$\pm 0.1\%$ F. S.
Temperature Effect:	Zero $\pm 0.007\%$ F. S. / $\%F$ (max) Span $\pm 0.007\%$ F. S. / $\%F$ (max)
Temperature Range:	0 $^{\circ}$ to 150 $^{\circ}\text{F}$ (-18 to 66 $^{\circ}\text{C}$)
Electrical Data:	Input 28 VDC Output 0-5 VDC
Sensotec, Inc. Columbus, Ohio Model TJE	
Principle:	Diaphragm with bonded strain gage
Range:	800-1034 mb (80-103.4 kPa)
Static Accuracy:	$\pm 0.1\%$ F. S.
Temperature Effect:	Zero $\pm 0.0025\%$ F. S. / $^{\circ}\text{F}$ Span 0.025/ $^{\circ}\text{F}$
Temperature Range:	0-160 $^{\circ}\text{F}$ (-18 to 71 $^{\circ}\text{C}$)
Electrical Data:	Input 10 VDC Output 3 mv/v

Table A2. Comparison of Selected Commercially Available Pressure Sensors
(Cont)

Setra Systems, Inc. Natick, Massachusetts Model C250	
Principle:	Capacitive pressure sensing capsule
Range:	800-1100 mb (80-110 kPa)
Accuracy:	± 0.3 mb (± 0.03 kPa)
Temperature Effect:	$< 0.002\%$ F.S. / $^{\circ}\text{F}$ ($< 0.004\%$ F.S. / $^{\circ}\text{C}$)
Operating Temperature Range:	0 $^{\circ}$ to 175 $^{\circ}\text{F}$ (-65 $^{\circ}$ to 250 $^{\circ}\text{F}$ optional (-18 to 80 $^{\circ}\text{C}$) temp effect ($< 0.004\%$ F.S. / $^{\circ}\text{F}$)
Electrical Data:	Input 24 VDC Output 0-5 VDC
Sperry Flight Systems Phoenix, Arizona Model ASI	
Principle:	Pressure sensitive vibrating diaphragm
Range:	27-32 in. Hg (91-108 kPa)
Accuracy:	± 0.005 in. Hg (± 0.02)
Electrical Data:	Input 115 VAC Output Digital
YSI-Sostman Yellow Spring, Ohio Model 2014	
Principle:	Capsule with potentiometric readout
Range:	745-1050 mb (74.5-105 kPa)
Accuracy:	$\pm 0.3\%$ of range span
Temperature Effect:	$< 0.0025\%$ F.S. / $^{\circ}\text{F}$ ($< 0.005\%$ F.S. / $^{\circ}\text{C}$)
Temperature Range:	-30 $^{\circ}$ to 185 $^{\circ}\text{F}$ (-34 to 85 $^{\circ}\text{C}$)
Electrical Data:	Requires Signal Conditioner